Dark Matter Searches with Liquid Nobles: Past, Present and Future

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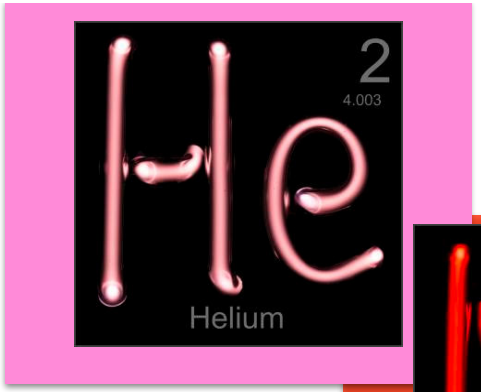
SLAC
(revised)

With Bernard Sadoulet

Liquid Nobles



Light WIMPs

Single Phase — **DEAP, MiniCLEAN**

Dual Phase — **DarkSide, ArDM**

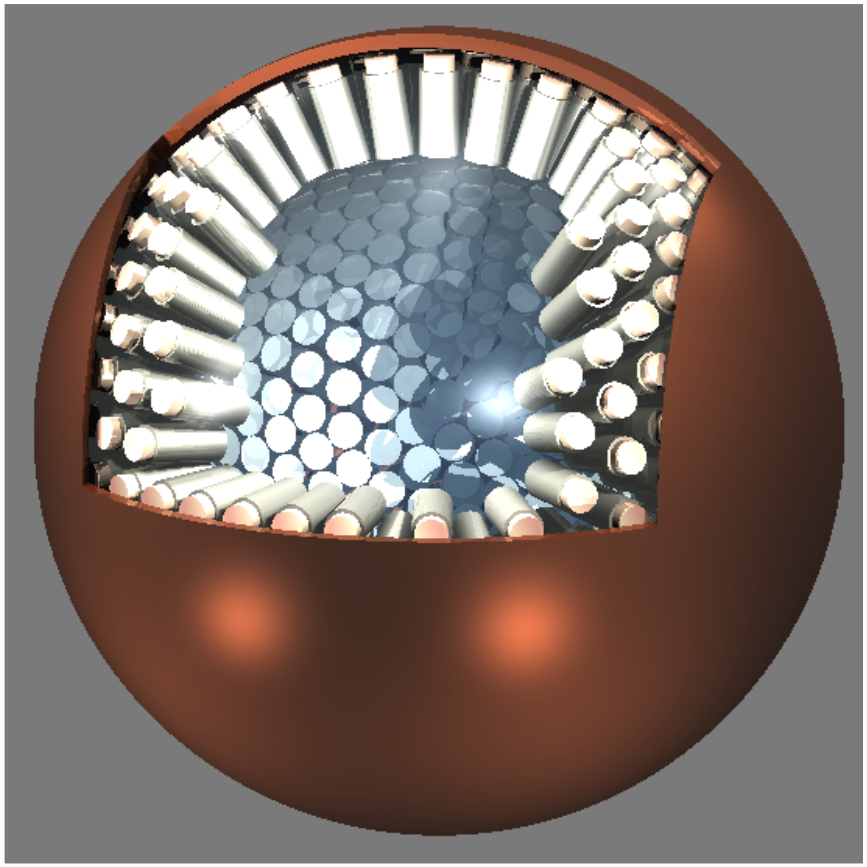
Single Phase — **XMASS**

Dual Phase — **LUX/LZ, XENON-100/1T/nT, Panda-X**

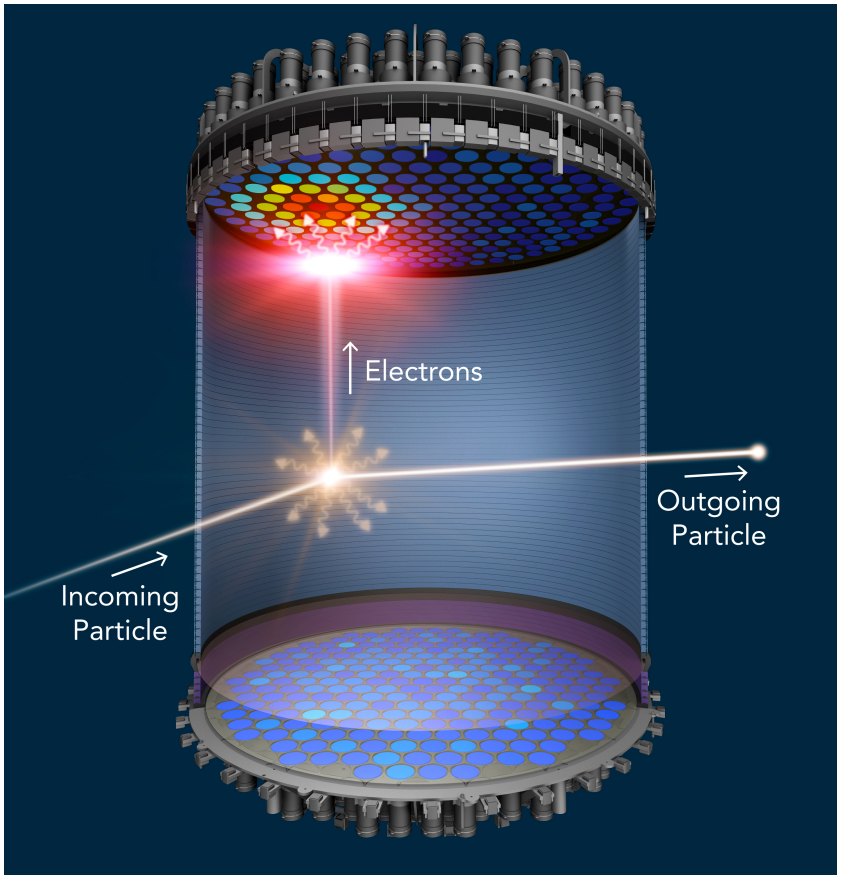
1 MBq/kg

discharge tubes from
http://periodictable.com

Single phase / Dual phase

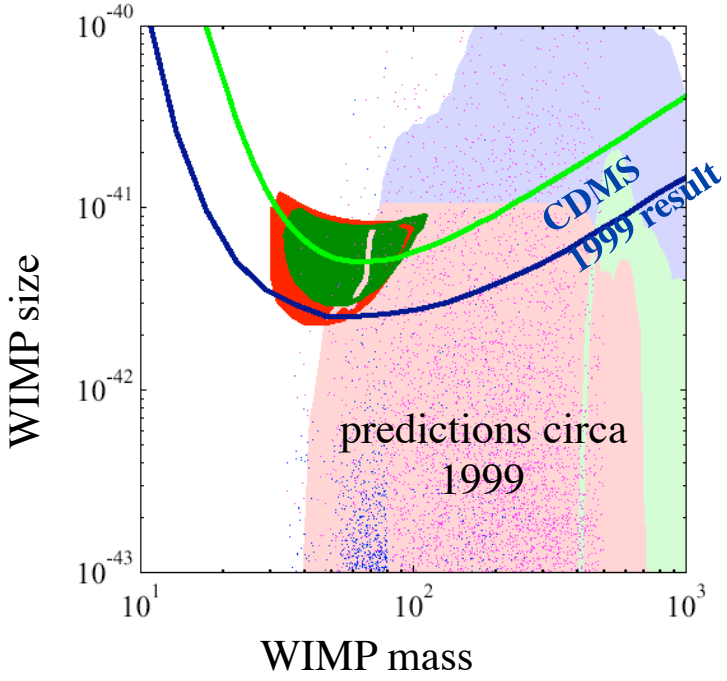


4π Scintillation

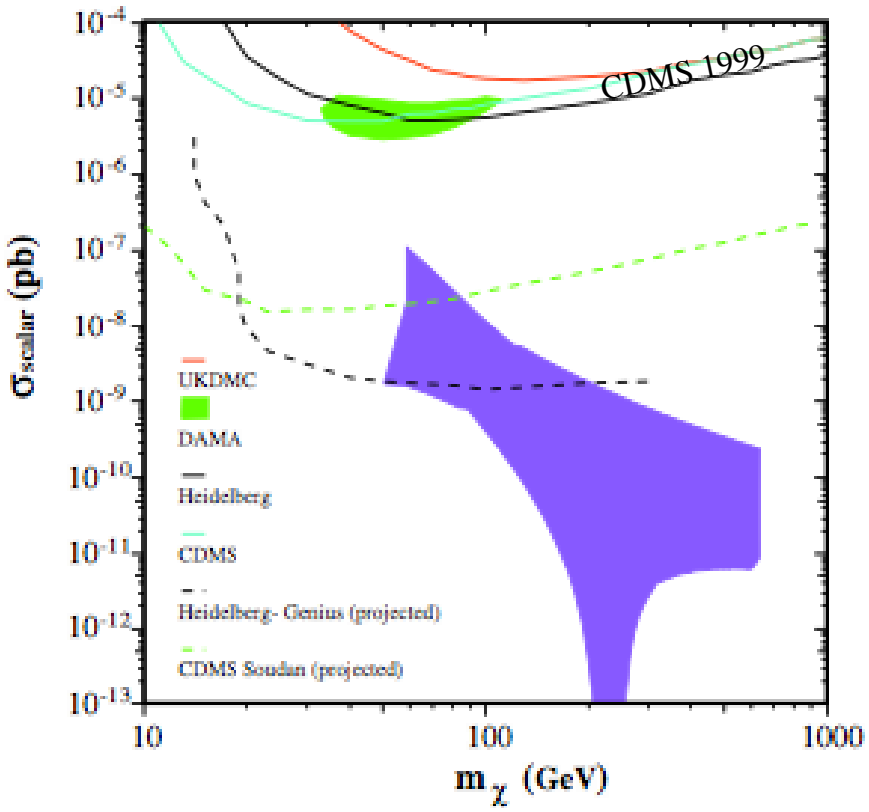


Time Projection Chambers (TPC)

Why liquid nobles?



J. Ellis, A. Ferstl, K. Olive, *PLB* 481 (2000)



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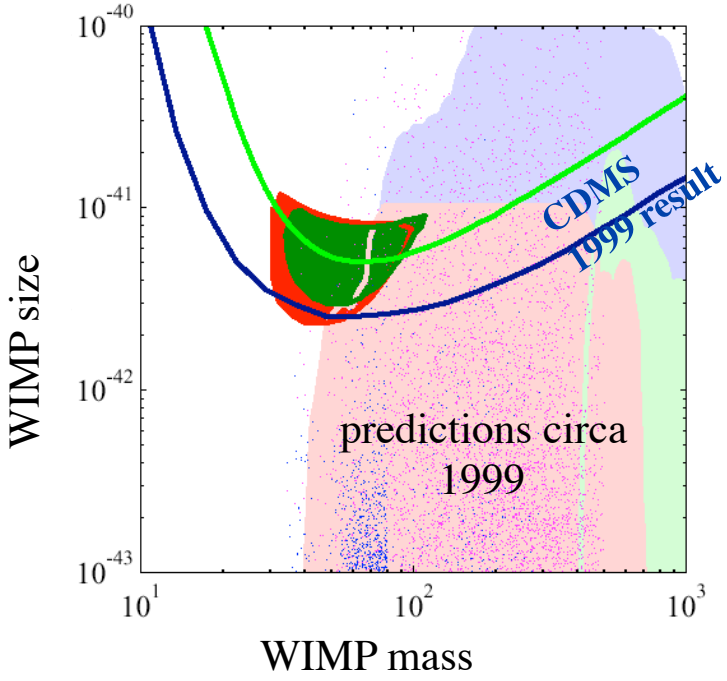
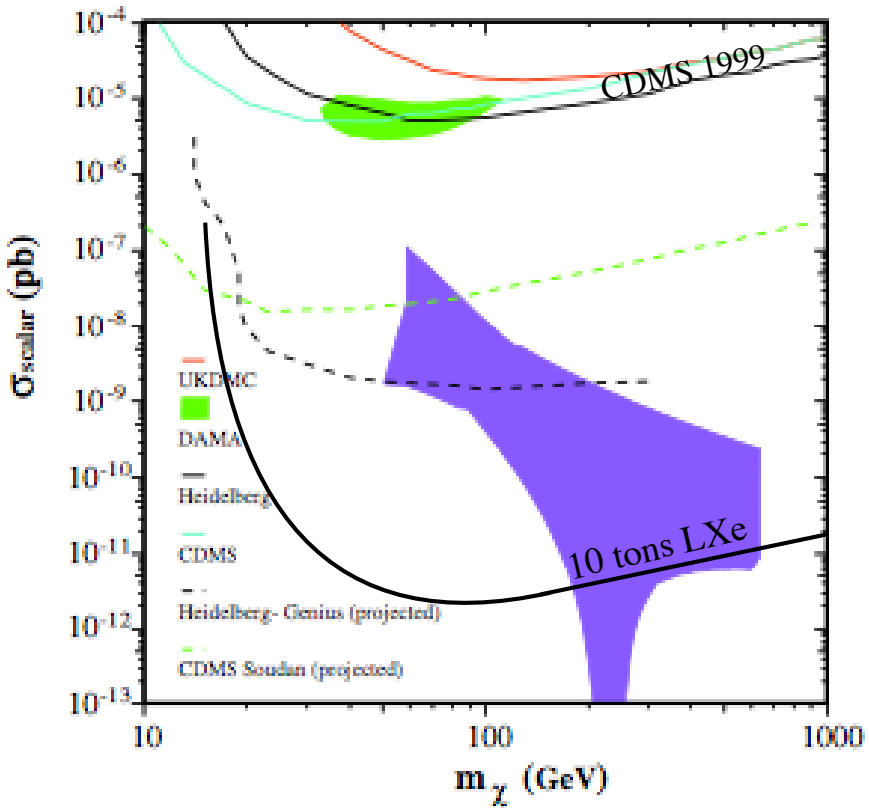


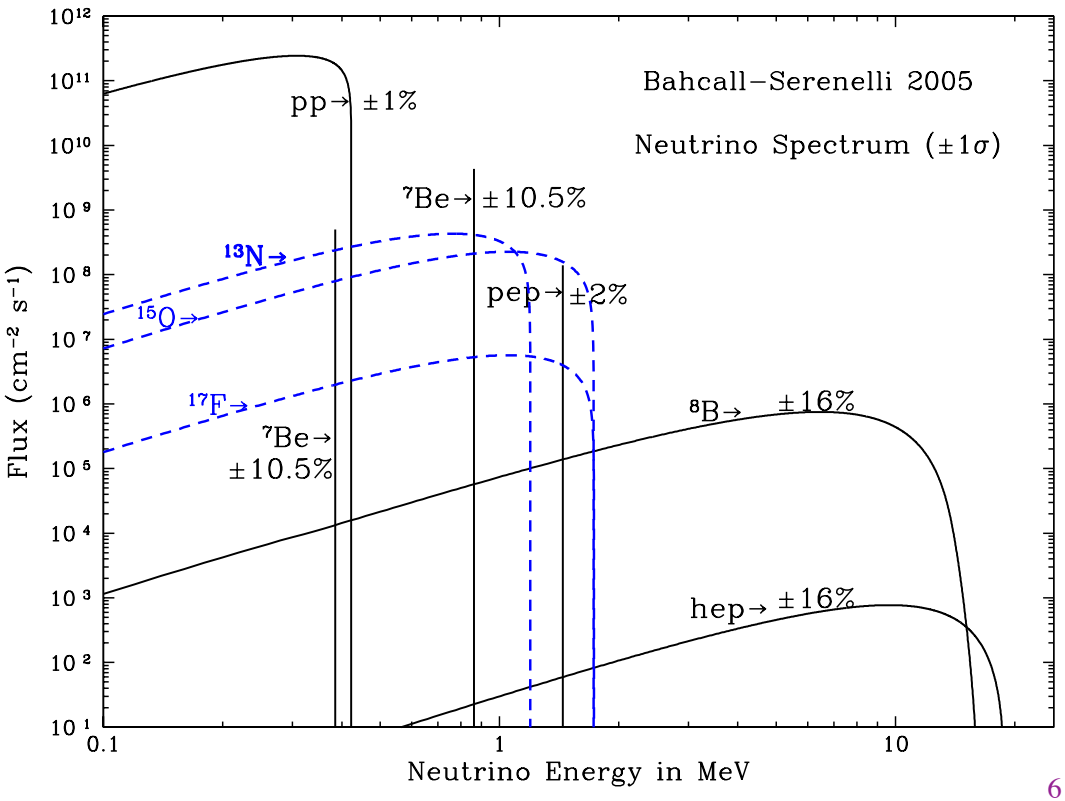


a predominant $U(1)$ gaugino (Bino) composition for the LSP. Our results fall considerably below many of the possible predictions in the literature [10], and may discourage some faint-hearted experimentalists. However, we think they provide a realistic estimate of the target

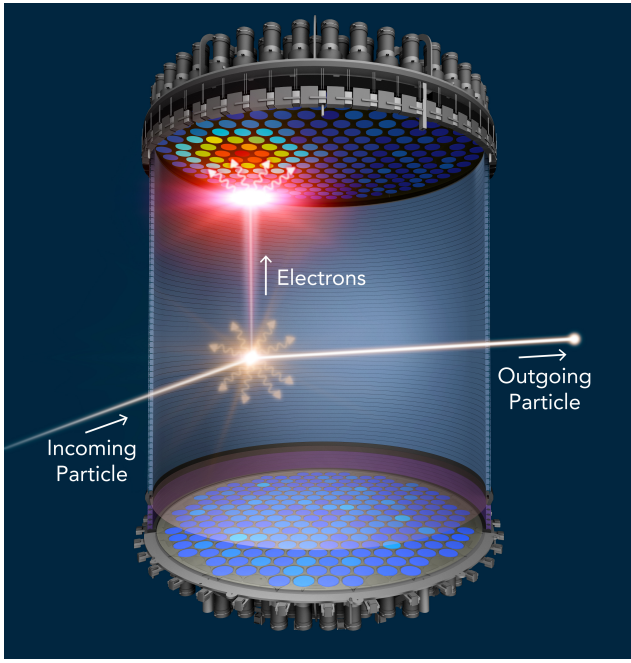
We should not want our experimental colleagues to be too downcast by the long road they appear to have to cover in order to probe the minimal universal MSSM framework utilized here. For example, there are surely some supersymmetric models that predict larger

SNO and Borexino

- SNO: measured deuterium dissociation
  - All gammas > 2.2 MeV suppressed. Th + U chains.
- Borexino: measured 862 keV ^{7}Be neutrinos
  - All backgrounds above ~200 keV suppressed. "Everything"
- Fiducial volume backgrounds extraordinarily low
  - Large detectors: Radioactivity (PMTs, SS) far from central volume
  - Disolved Rn, and Kr+Ar (Borexino)
  - Borexino internal Rn < 0.57 cnts/ day/100 tons is 1/1000 of pp signal at 5 keV.
  - SNO somewhat higher, but in *water.*
- Can't see dark matter: ^{14}C
  - Suppressed by 10^{6} in petrochemicals, still too high



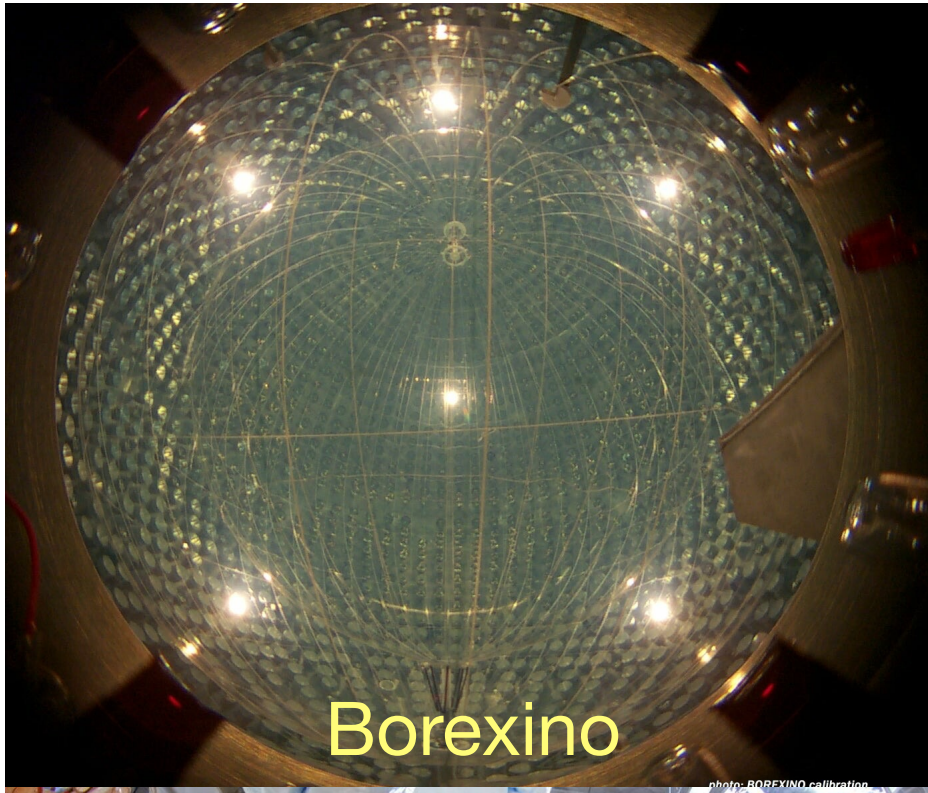
Two Phase Detectors



- Alvarez, LBL, suggested LAr/LXe, 1968. But charge multiplication difficult
- Two phase detector developed in Russia - Dolgoshein, 1970
- TPC- Nygren, LBL, late 70s
- LXe, LAr technology developed in Japan, Columbia group through 90s.
- LXe for DM- mid 90's UK, UCLA + others. ZEPLIN II proposal - 98. Then XENON, 2001 onward.
- LAr - WARP, 2004. From ICARUS. ^{39}Ar not considered
- Modern geometry emerged over time
  - PMTs inside our outside? In liquid?
  - Waveshifter? CsI photocathode with no PMTs?
  - Unreasonably high reflectivity of PTFE in LXe not initially recognized
  - S2 for nuclear recoils not clearly measured until 2003/4 (XMASS/Case)
  - Emerged in ZEPLIN II design, but argument settled with success of XENON10
- Current experiments enabled by low background PMTs - synthetic quartz necessary for 175 nm Xe scintillation
  - Borexino PMTs - 3×10^{6} mBq/m^2
  - Current PMTs (@1mBq) - 200 mBq/m^2.
  - LAAPD (EXO) < 0.06 mBq/m^2.

Single Phase

- LXe - UKDM, 1994 - ZEPLIN I.
  - PSD, but turns out poor in LXe
- *pp* Solar Neutrino-inspired detectors
  - LXe - XMASS, 2000. Also ßß decay, DM
  - Ne - McKinsey+Doyle, 1999. Also DM. Considered PSD, but data lacking.
  - PSD in LAr: Hime/Boulay 2004 - should overcome ^{39}Ar background
- Surfaces very important - Rn daughters
  - Rayleigh scattering prevents timing-based position reconstruction.



Signal production in liquid Xe & Ar

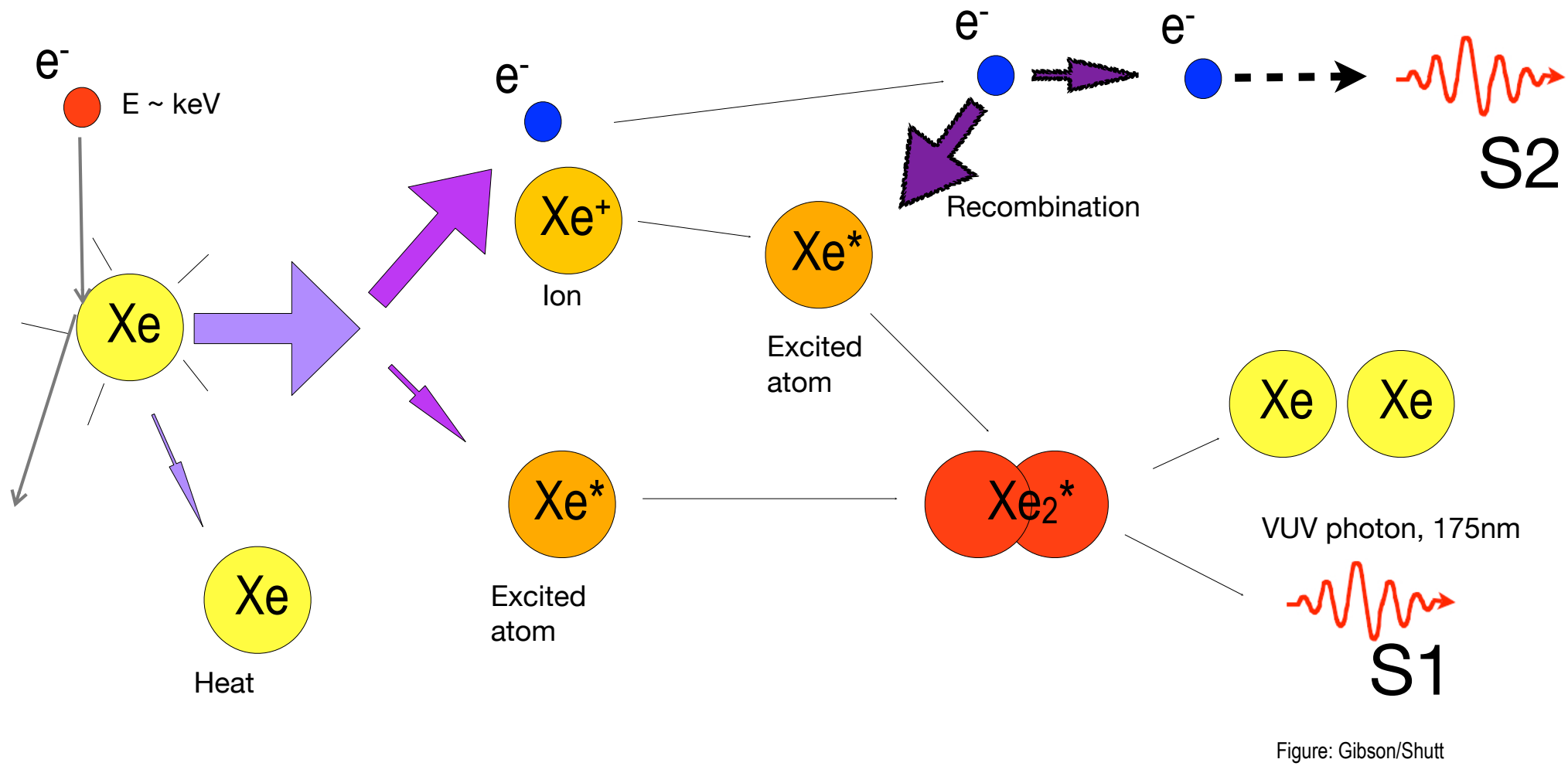


Figure: Gibson/Shutt

Electron Recoils

Low field, low energy

Signal production in liquid Xe & Ar

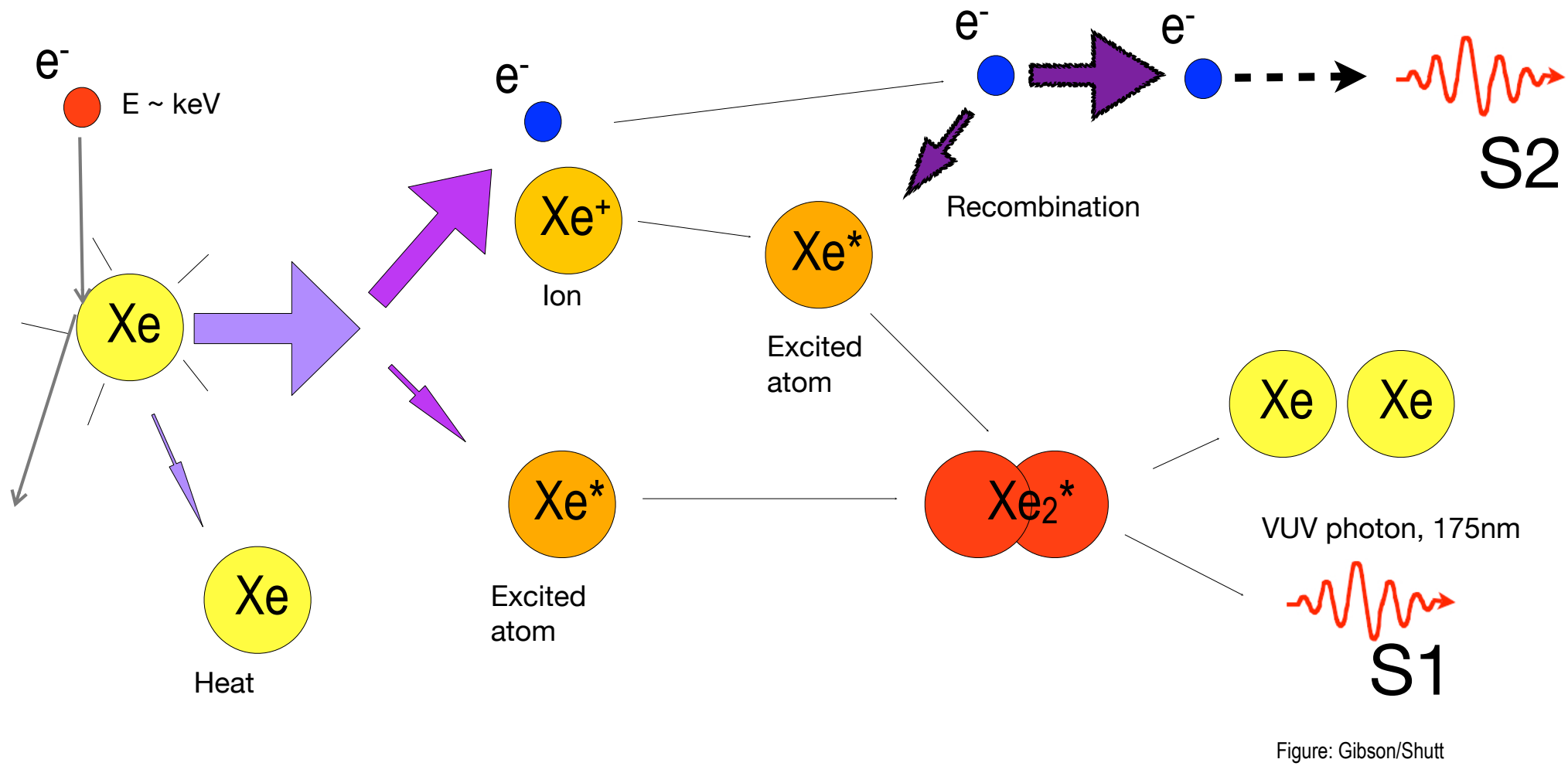


Figure: Gibson/Shutt

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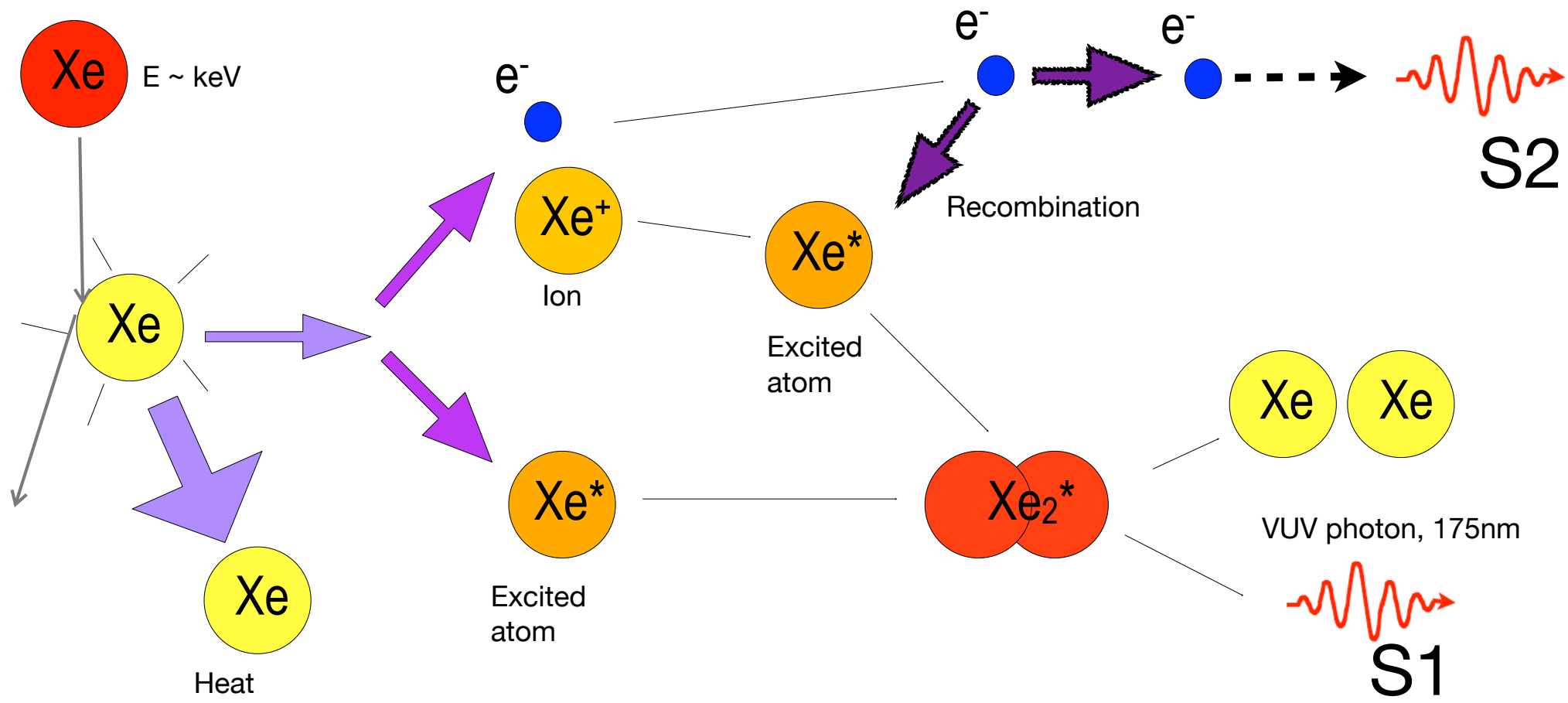
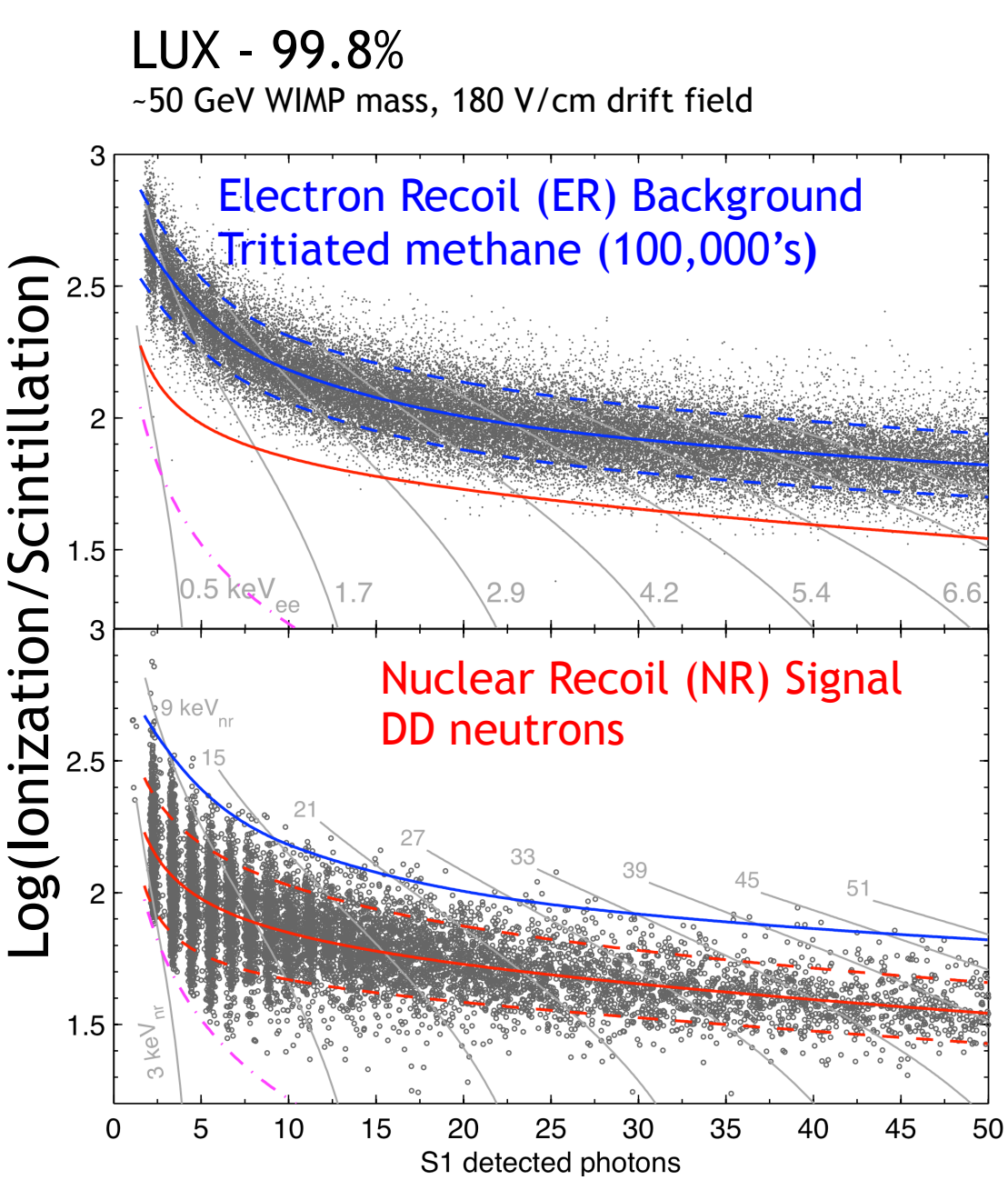


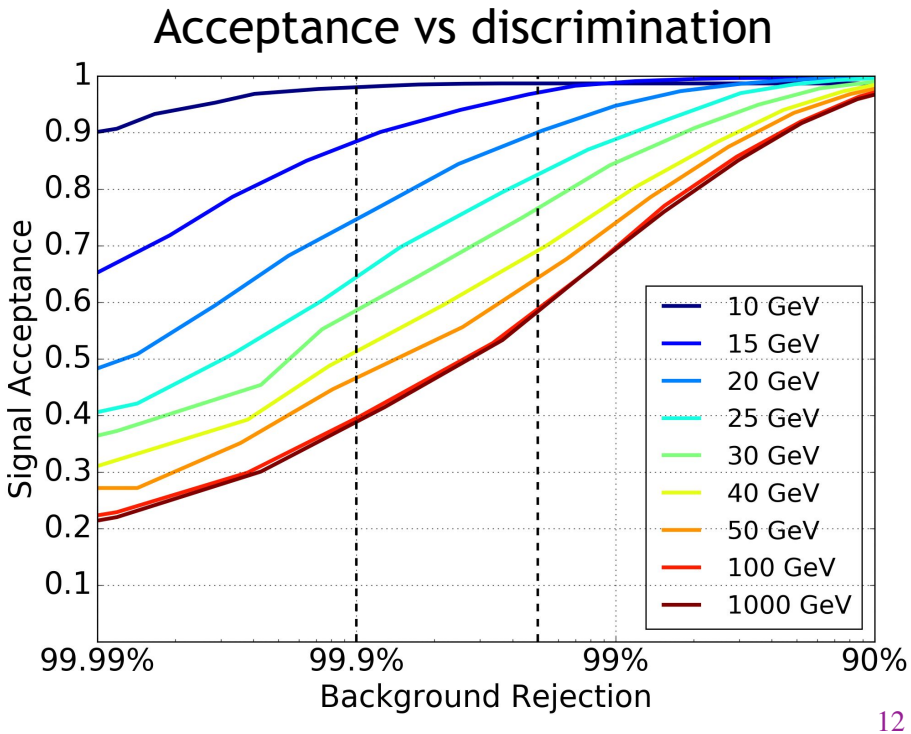
Figure: Gibson/Shutt

Nuclear Recoils

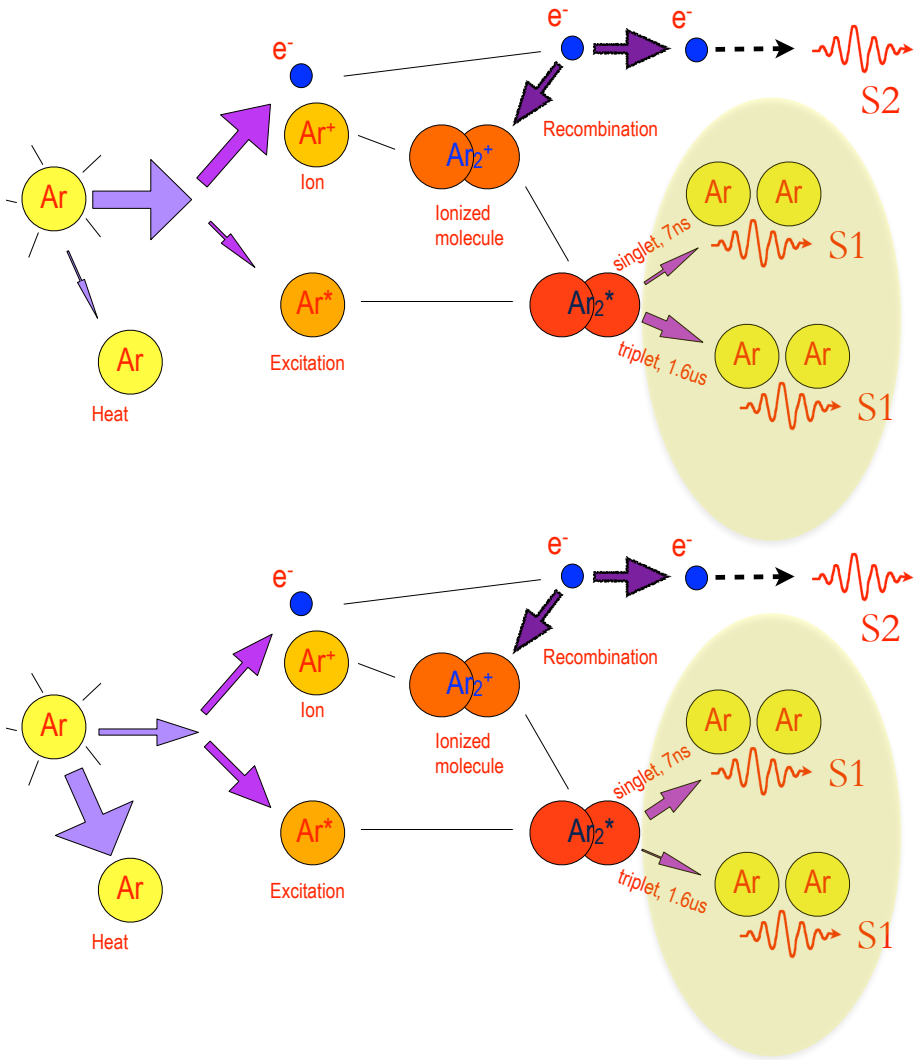
LXe Charge/Light Discrimination

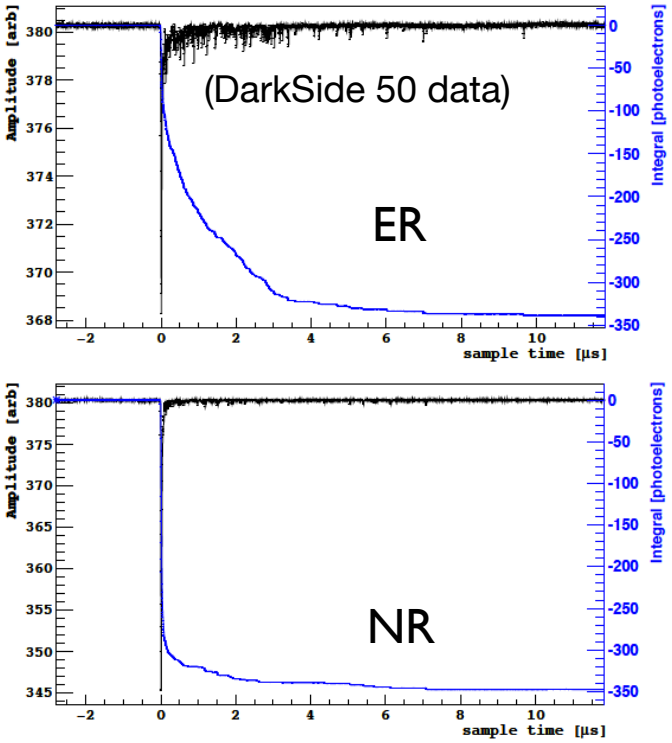


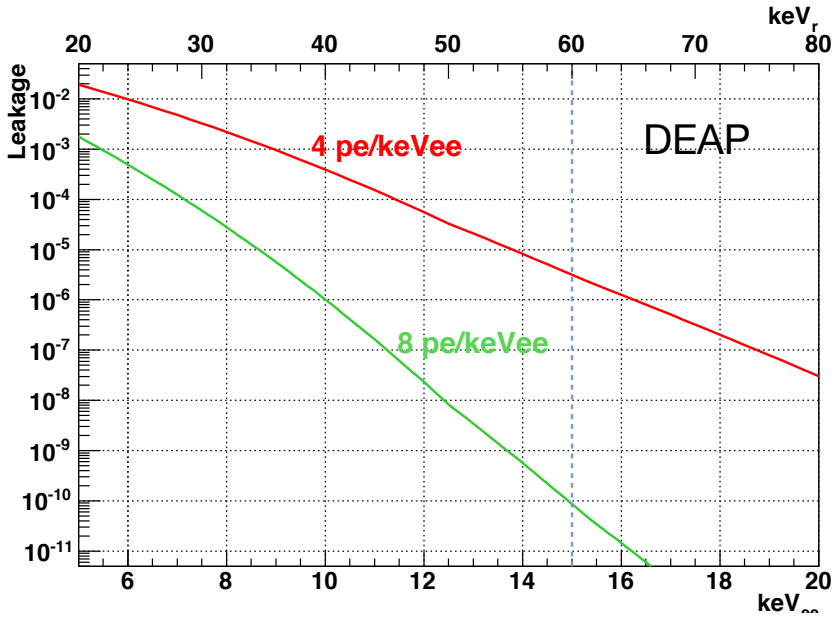
- Remarkably, discrimination strongest at lowest energy
- High discrimination, at reduced acceptance
  - (Likelihood technique avoids explicit choice)



Pulse Shape Discrimination (PSD) in LAr

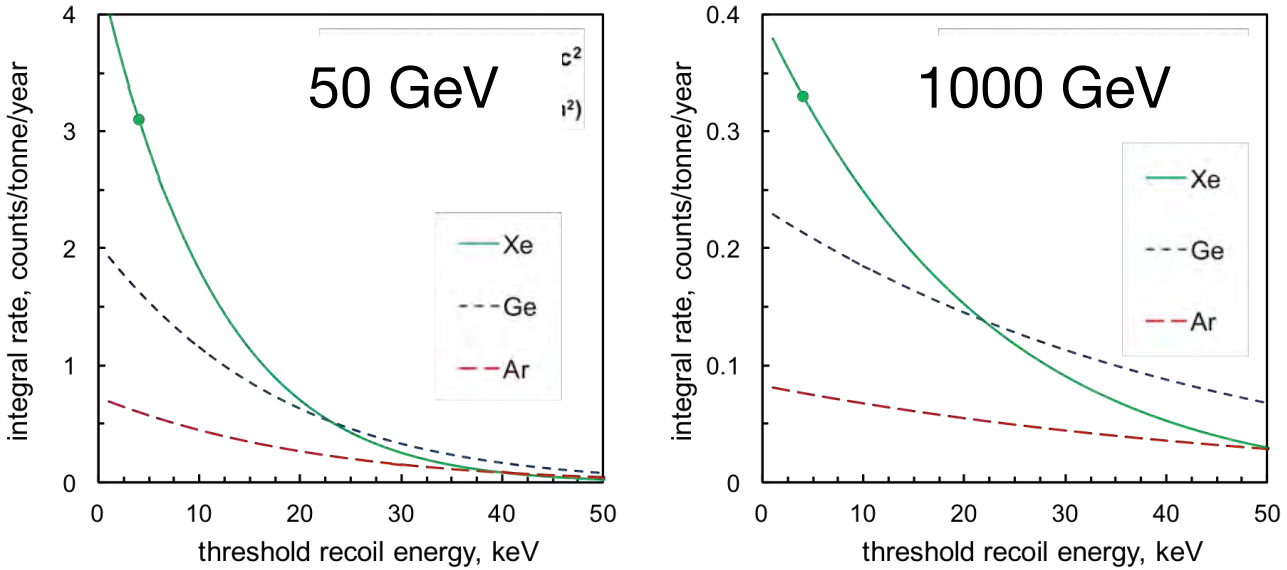




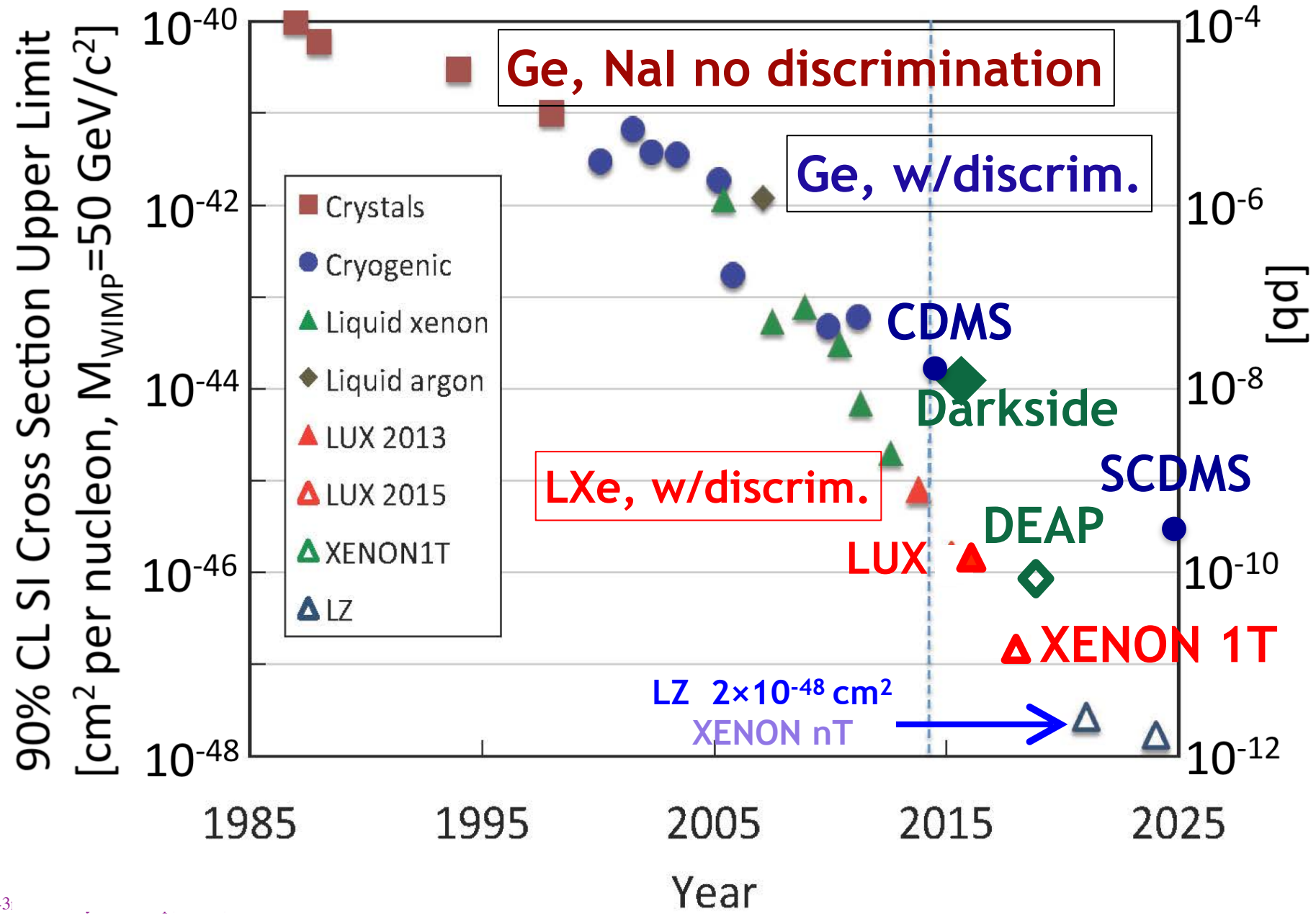


Reaching the floor

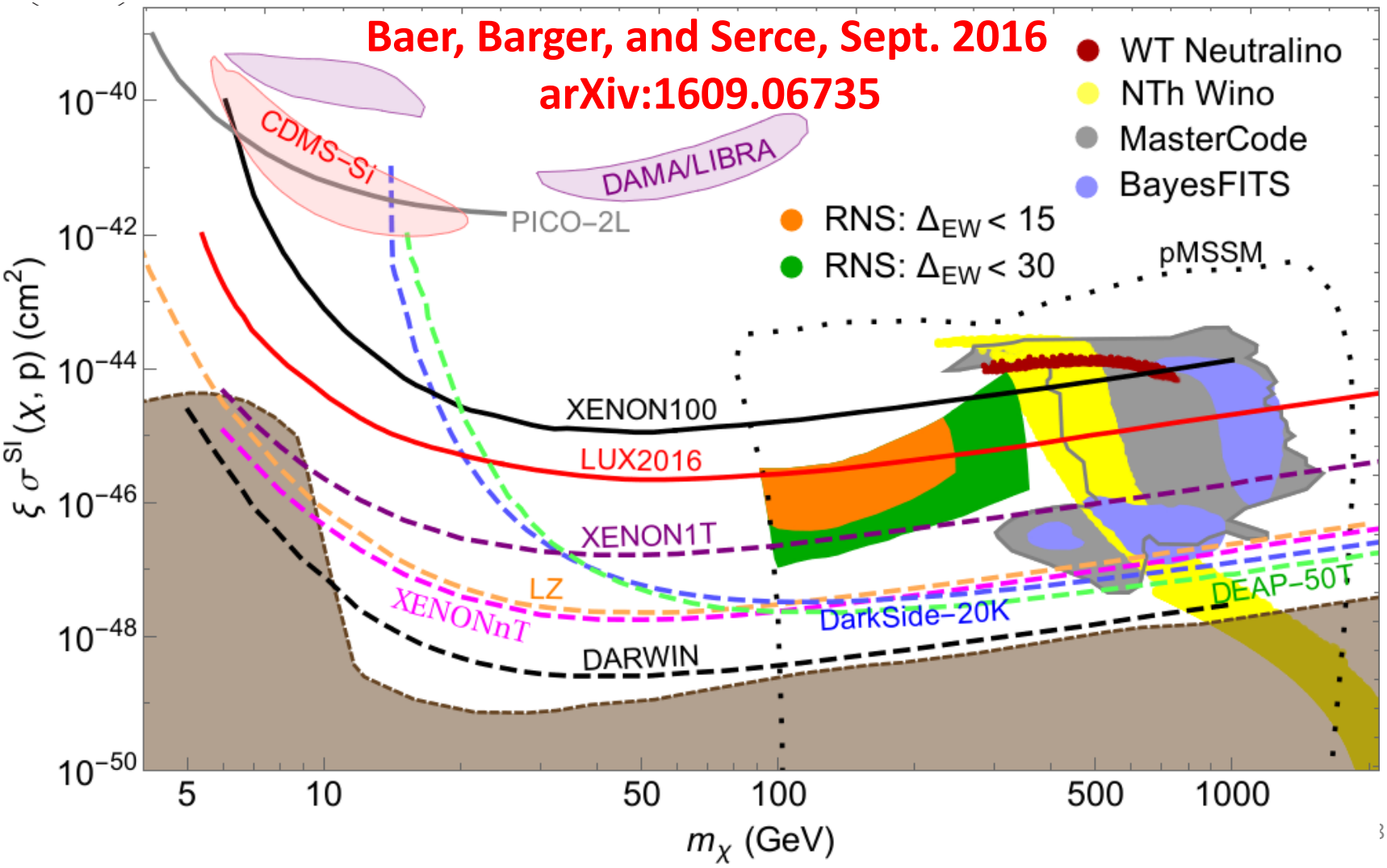
- Floor was noticed - Rubbia, 2004. Strigari, 2009.
- Bohr/Berra lemma: Predictions are difficult, especially about the future.
- Xe, Ar. My opinion: both can reach neutrino floor.
  - Xe discrimination - what is acceptance with deployed light collection and field?
  - Ar PSD is sufficient. How much does S2/S1 add? What is best way forward on ^{39}Ar?
  - Only question of cost. Can be estimated for LXe



Faster than Moore



Plenty of room for discovery



Can nobles go low?

- LAr - limited by vanishing PSD at low energy
- LXe - somewhat
  - ~5 keVnr S1+S2, limited by light collection. Factor of ~3 light collection on table.
  - Lower, with electrons only (Sorenson). Backgrounds not understood.
  - Dope LXe with Ne or even He?
- LHe
  - HERON pp neutrino effort in 80s and 90s
  - Several modes measurable
  - Modern cryodevices enabling - TES and related
  - See D. McKinsey's talk tomorrow

Combined ββ decay and Dark Matter?

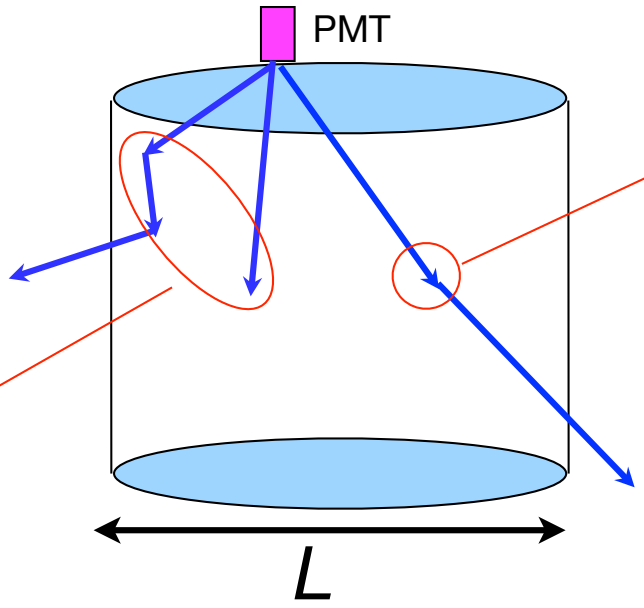
- LXe TPCs for DM and ββ decay superficially very similar, so far different in detail
- ββ decay has much more stringent radioactivity goals - poorer self-shielding, no discrimination
- DM needs single PE sensitive high efficiency light readout, but PMTs too hot. SiPMs promising.
- Probably makes sense at 50-ton / G3 scale

Gammas, neutrons
λ ~10 cm

Penetration probability

$$P(x) = e^{(-\frac{x}{\lambda})}$$

ββ background



DM ER background

$$P \cong \frac{L}{\lambda} e^{(-\frac{L}{\lambda})}$$